

# Advanced Computing for 21<sup>st</sup> Century Accelerator Science and Technology

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Robert Ryne

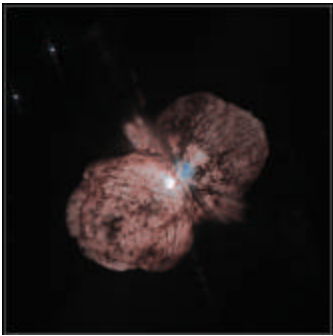
Lawrence Berkeley National Laboratory

for the

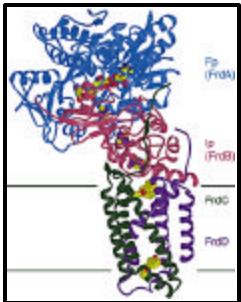
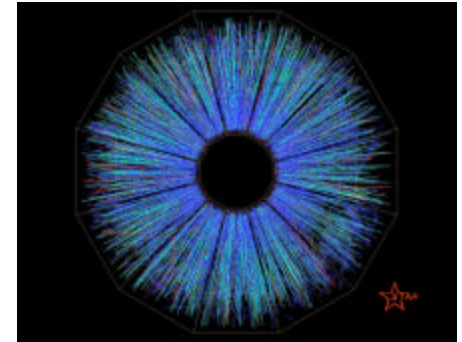
SciDAC accelerator modeling project team

# Accelerators are Crucial to Scientific Discoveries in High Energy Physics, Nuclear Physics, Materials Science, and Biological Science

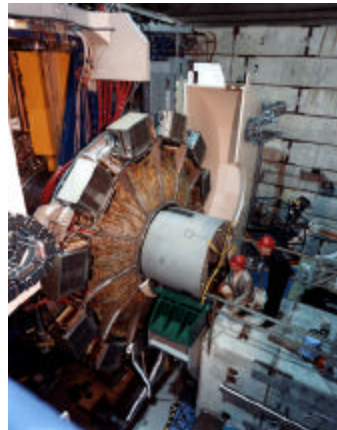
*“Starting this fall, a machine called RHIC will collide gold nuclei with such force that they will melt into their primordial building blocks”*



*“A new generation of accelerators capable of generating beams of exotic radioactive nuclei aims to simulate the element-building process in stars and shed light on nuclear structure”*



*“Biologists and other researchers are lining up at synchrotrons to probe materials and molecules with hard x-rays”*



*“Violated particles reveal quirks of antimatter”*

*“Muon Experiment Challenges Reigning Model of Particles”*



# The National Investment in Particle Accelerators is Enormous



Lawrence Berkeley Natl. Lab.  
**ALS**



Indiana Univ.  
**IUCF**



Fermi National Acc. Lab.  
**Tevatron**



Michigan State Univ.  
**NSCL**



Argonne National Lab.  
**IPNS ATLAS APS**



Cornell Univ. **CESR CHES**



Stanford Linear Acc. Center  
**SLC PEP-II SSRL**



Los Alamos Natl. Lab.  
**LANSC/Lujan**



Oak Ridge National Lab.  
**SNS**



Thomas Jefferson National  
Accelerator Facility: **CEBAF**

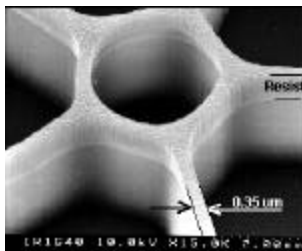
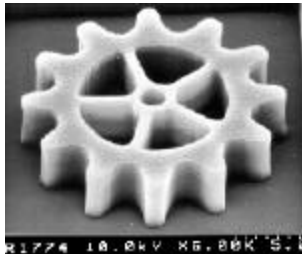


Brookhaven National Lab.  
**RHIC NSLS**

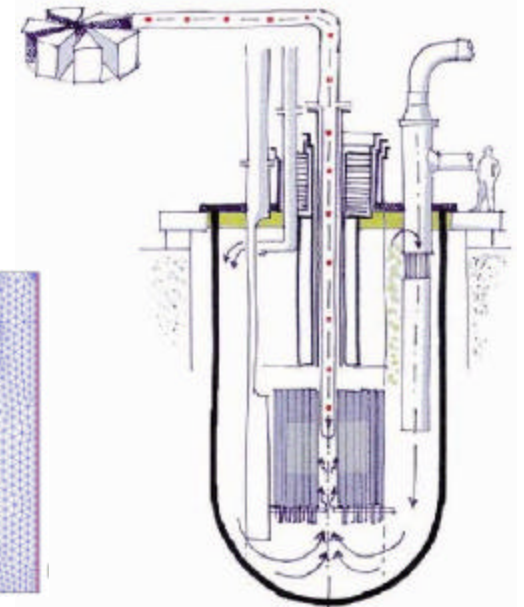
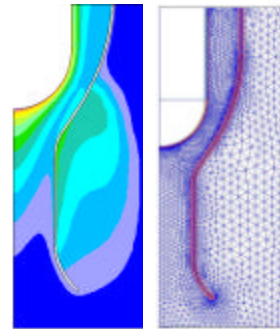


# Contributions of accelerators have significant economic impact and greatly benefit society

- Medical isotope production
- Electron microscopy
- Accelerator mass spectrometry
- Medical irradiation therapy
- Ion implantation
- Beam lithography

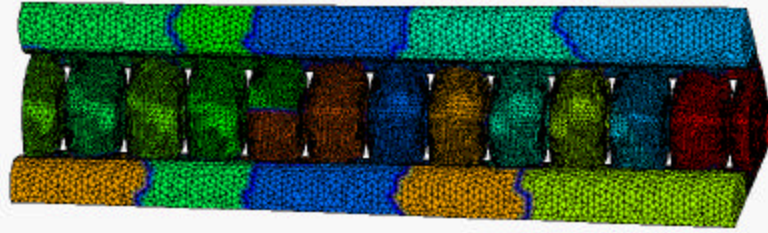


- Transmutation of waste
- Accelerator-driven energy production
- Hydrodynamic imaging

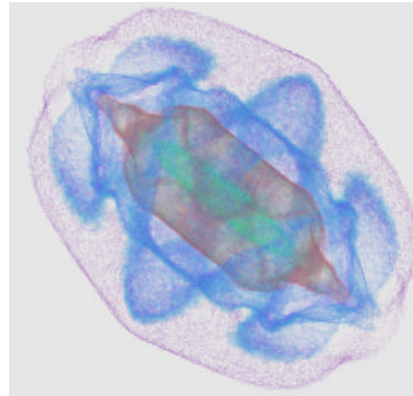


# The accelerator community uses high performance computing to tackle of wide range of problems

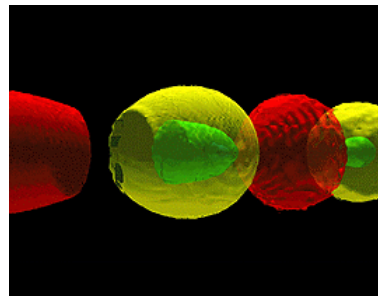
- Designing complicated electromagnetic structures



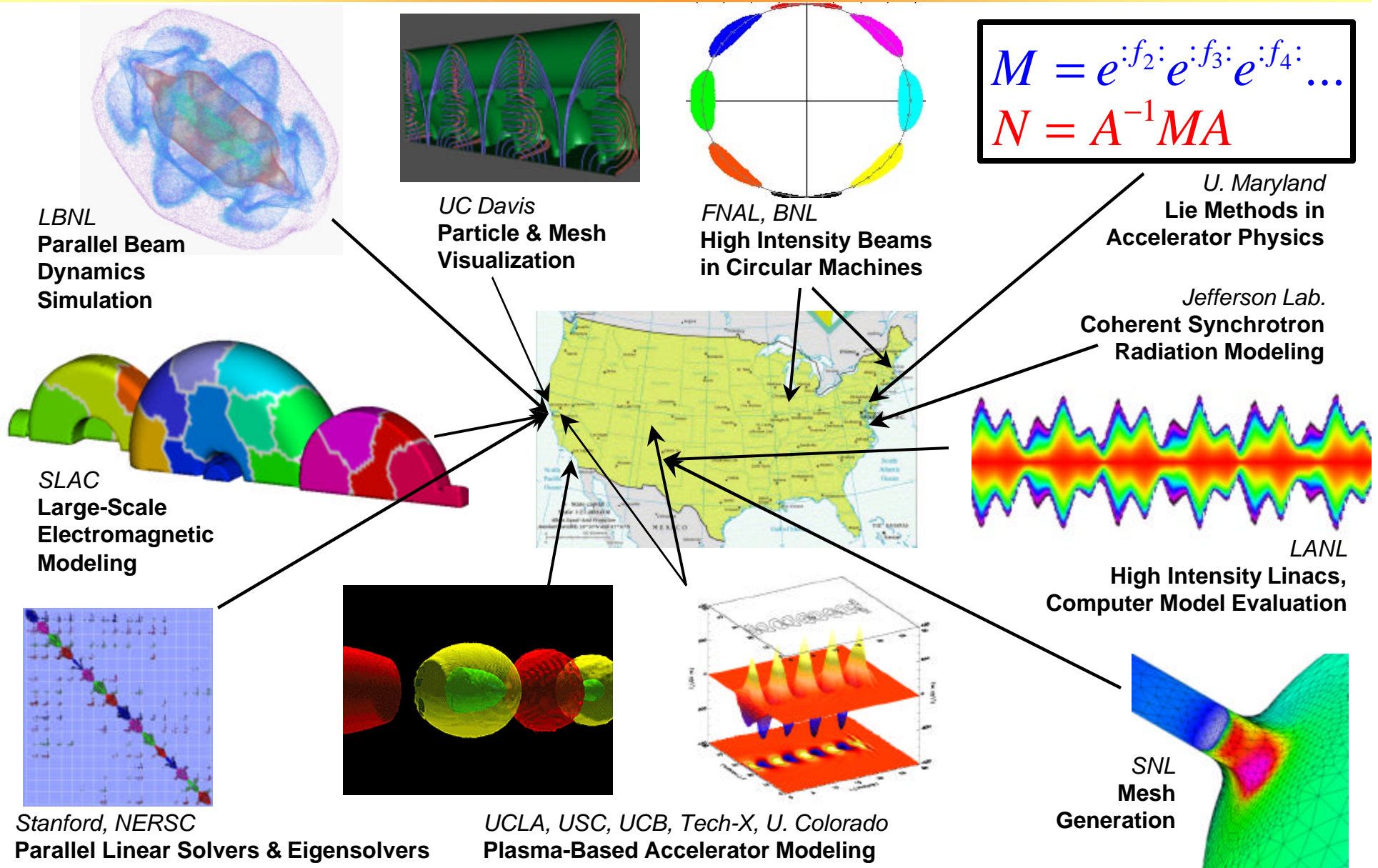
- Modeling high intensity beam dynamics



- Exploring beams under extreme conditions



# Accelerating Scientific Discovery in Accelerator Technology and Beam Physics: A SciDAC Multi-disciplinary, Multi-institutional Collaboration



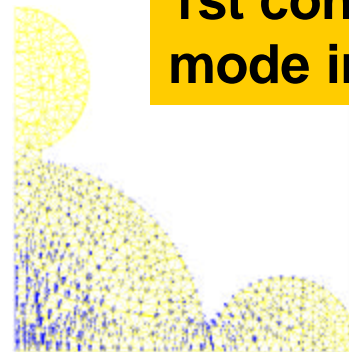
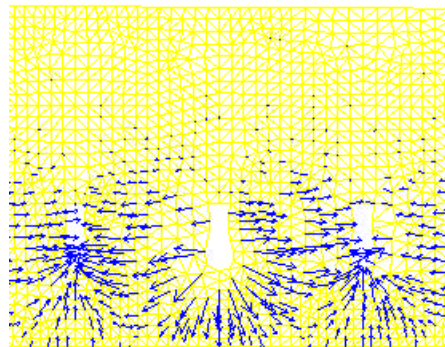
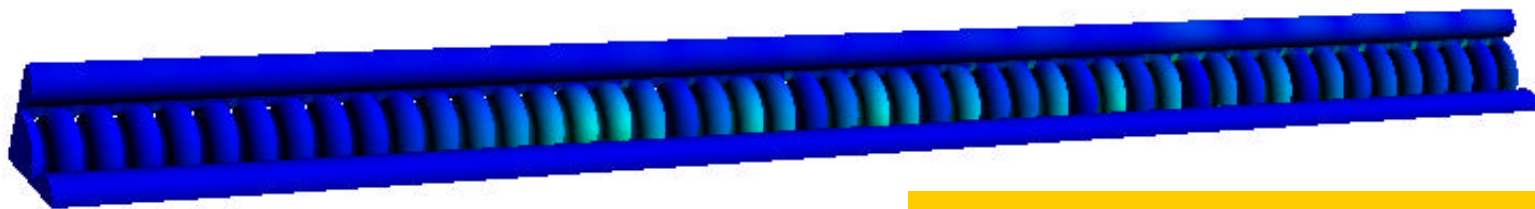
# Noteworthy accelerator computations performed at NERSC

- First successful 3D eigenmode calculation of ~50 cell Next Linear Collider (NLC) structure including accelerating cells and damping manifold
- First self-consistent 3D Fokker-Planck simulation
- Simulations identified possible heating mechanism in PEP-II B-factory interaction region
- Simulations in support of SLAC E-157 plasma wakefield accelerator experiment
- Simulations in support of Spallation Neutron Source linac design effort and the LANL/LEDA beam halo expt
- Simulations in support of CERN/SPL design effort (similar to US neutrino factory design effort)

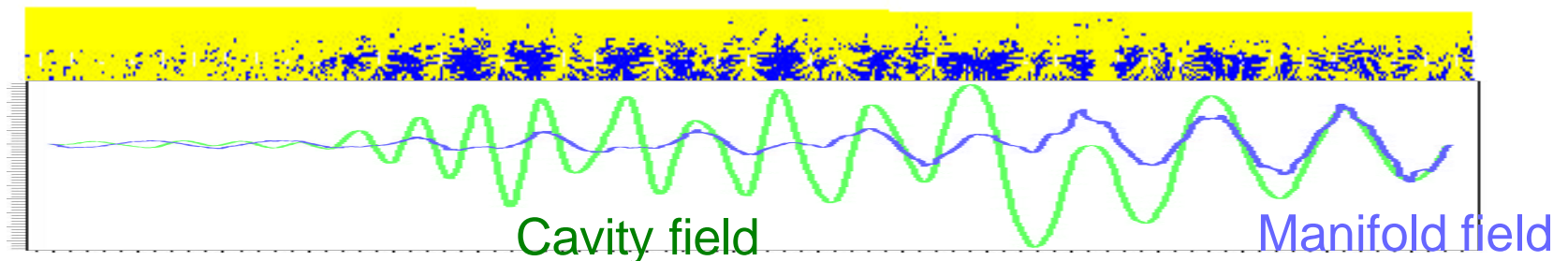


# NLC RDDS 47 Cell Stack - *Omega3P*

*Calculation of modes in entire structure has begun*



**1st convergence of a mode in a dense spectrum**

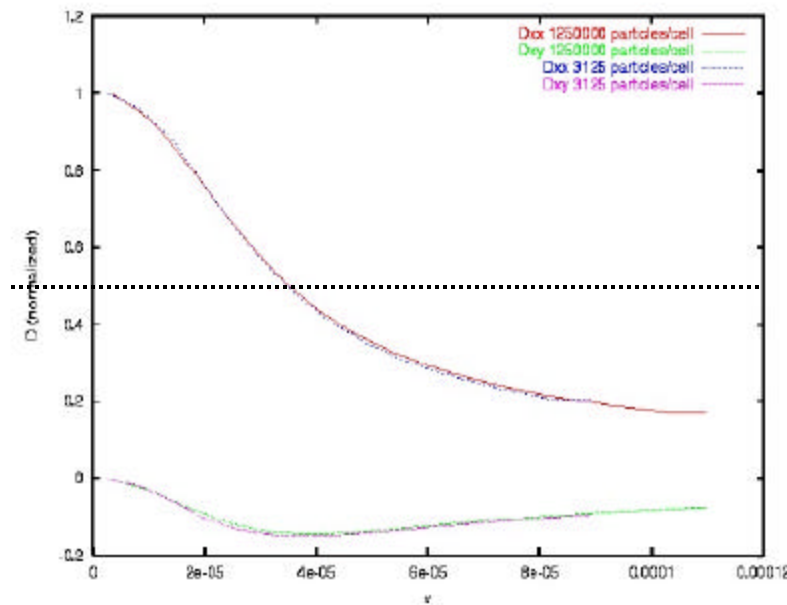




# 3D First-Principles Fokker-Planck Simulation

- Requires analog of 1000s of space-charge calculations/step
  - “...it would be completely impractical (in terms of # of particles, computation time, and statistical fluctuations) to actually compute [the Rosenbluth potentials] as multiple integrals” J.Comp.Phys. 138 (1997).
- Feasibility demonstrated!

Self-Consistent  
Diffusion  
Coefficients

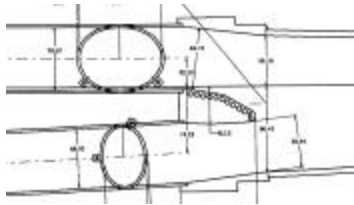


← Spitzer  
approximation

Previous approximate  
calculations performed  
w/out parallel computation  
were not self-consistent

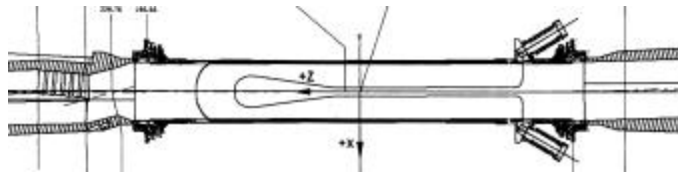
# PEP II - IR Beamline Complex

*Left crotch*



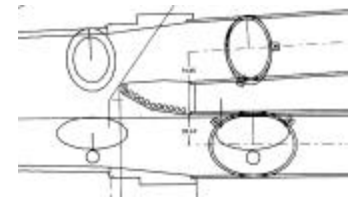
2.65 m

*Center beam pipe*



2.65 m

*Right crotch*



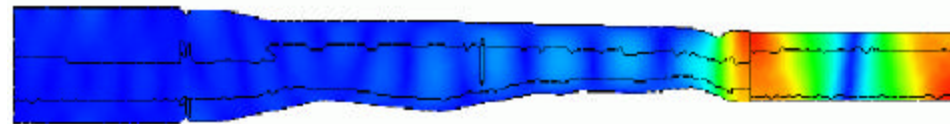
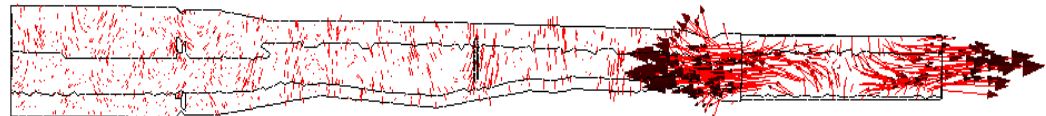
$e_+$

$e_-$

*Identify localized modes to understand beam heating*

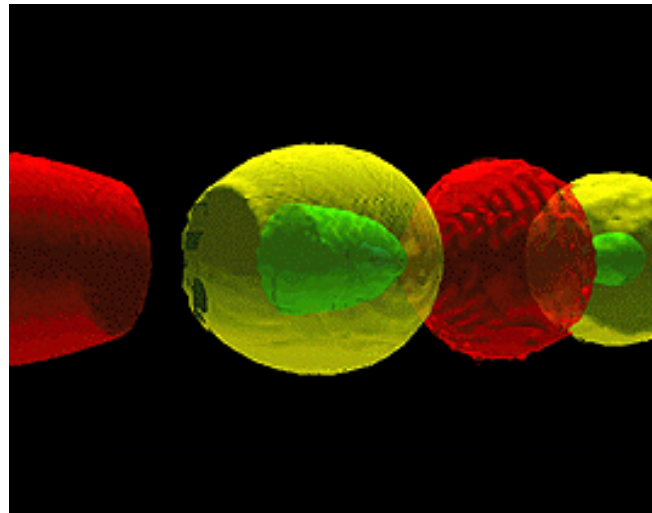


Short section from IP



# Laser/Plasma-based acceleration can produce gradients $\sim 100 \text{ GeV/m}$

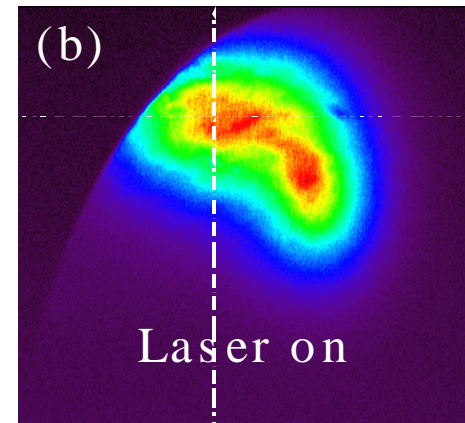
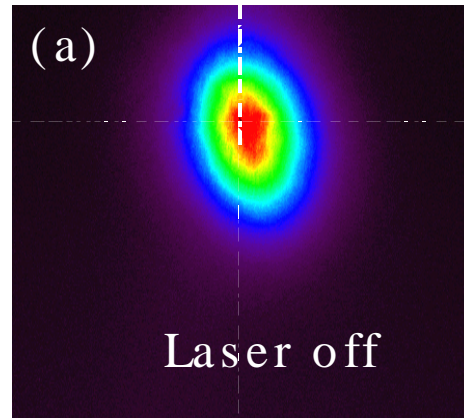
- High gradients measured in the lab over short distances
  - 100s to 1000s times greater than conventional technology
- **Plasma wakefield accelerator** (PWFA) concept uses extremely high fields in plasmas



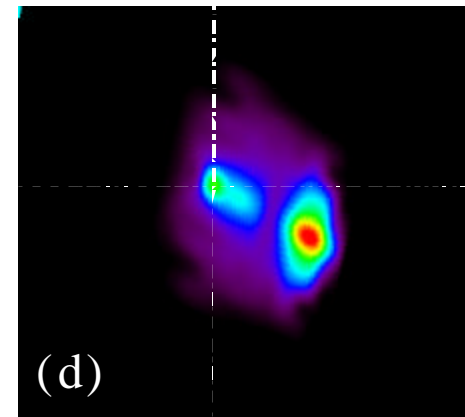
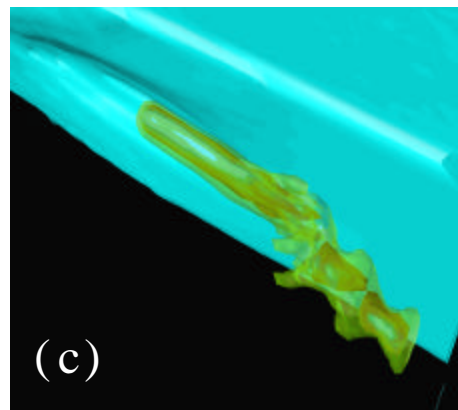
- **Challenge is to control & stage** high-gradient sections to produce a high quality, high energy beam
- Simulation of 1-10 GeV PWFA would require  $\sim 10\text{K}-100\text{K}$  CPU-hours

# Direct comparison between expt and full-scale PIC simulation using OSIRIS of the refraction of a 30 GeV $e^-$ beam at a plasma vacuum interface

Experiment



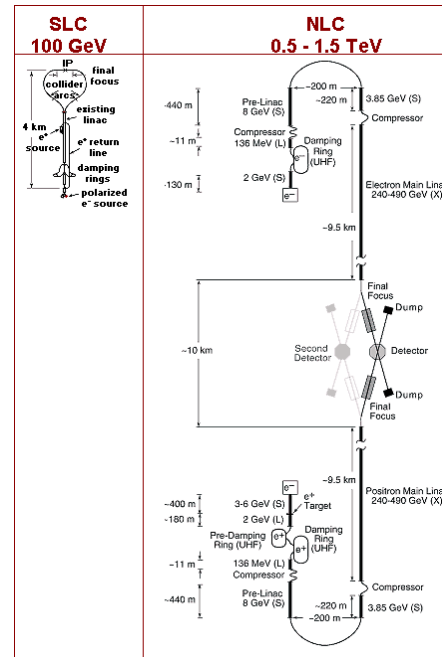
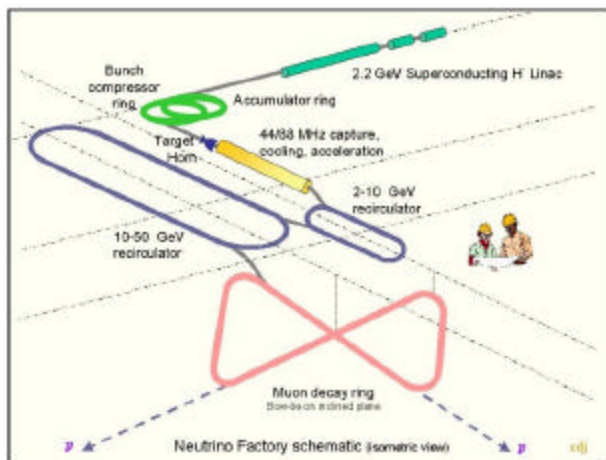
PIC Simulation



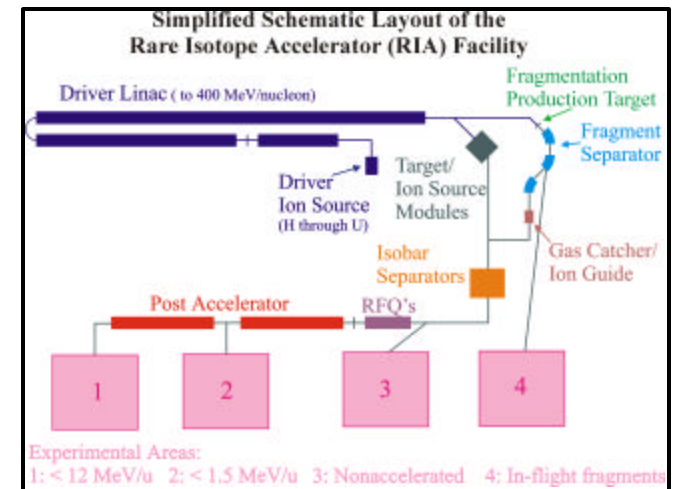


# Opportunities at Next-Generation Accelerator Facilities

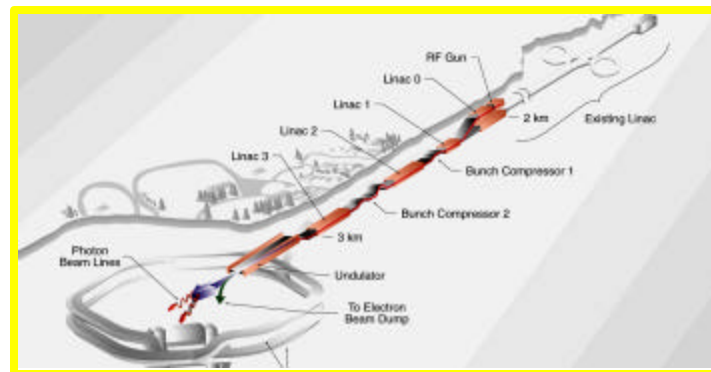
*Exploring physics beyond the Standard Model. Are there new particles? New interactions?*



*Research with exotic nuclei:  
The nature of nucleonic matter; origin of the elements; tests of the Standard Model*



*Research using intense, ultra-short pulses of x-ray radiation (4<sup>th</sup> generation light source):  
fundamental quantum mechanics; atomic, molecular, and optical physics; chemistry; materials science; biology*



# HPC will play a major role

- **Present accelerators:** Maximize investment by
  - optimizing performance
  - expanding operational envelopes
  - increasing reliability and availability
- **Next-generation accelerators**
  - better designs
  - feasibility studies
  - Facilitate important design decisions
  - completion on schedule and within budget
- **Accelerator science and technology**
  - help develop new methods of acceleration
  - explore beams under extreme conditions

